Soil Acidity

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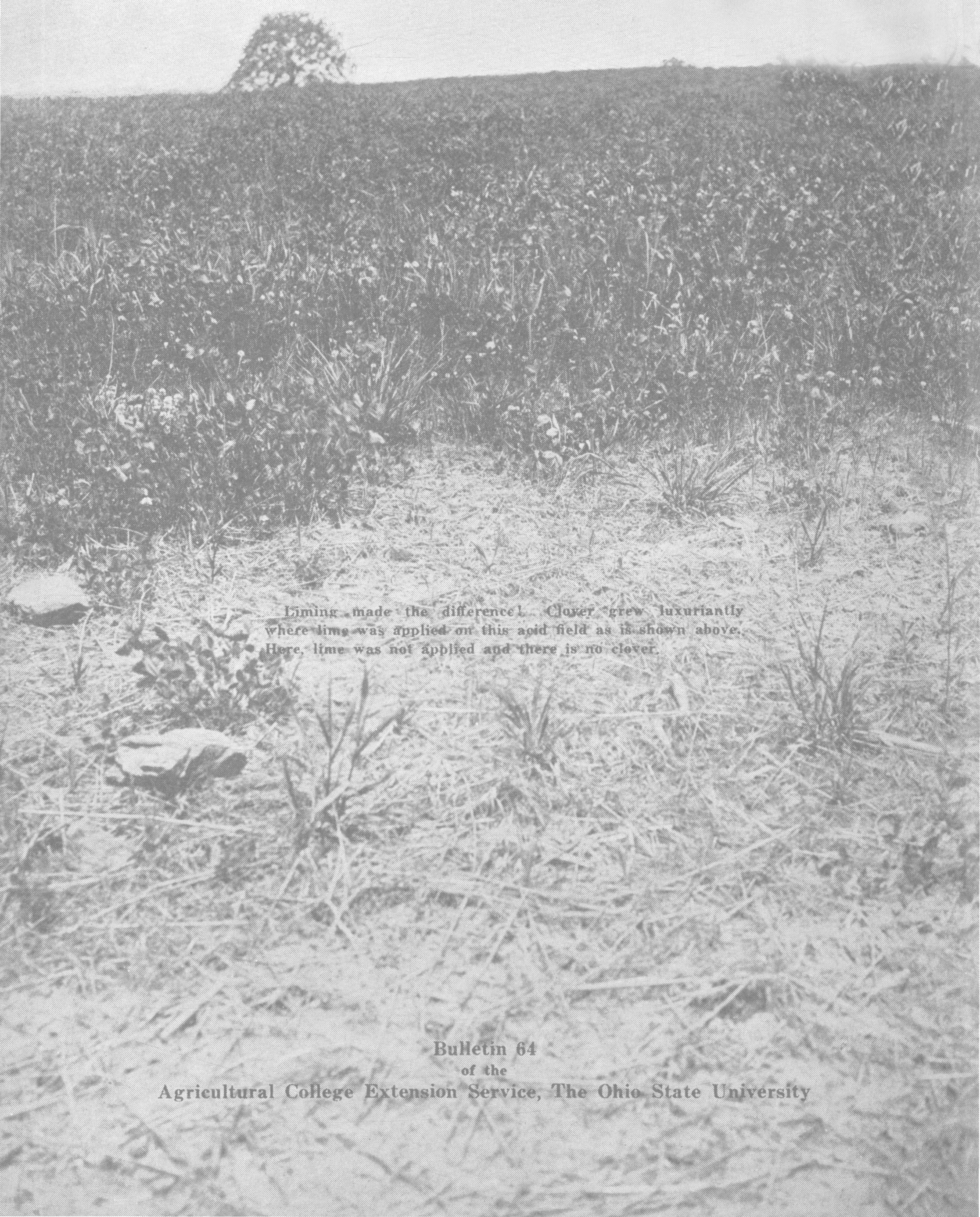

Liming made the difference! Clover grew luxuriantly where lime was applied on this acid field as is shown above. Here, lime was not applied and there is no clover.

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THE PROBLEM OF SOIL ACIDITY

By E. E. Barnes

Where Acid Soils Are Found

IT IS INTERESTING to note that acid soils are found only in regions of relatively high rainfall; in arid regions, alkali soils are found instead. The one hundredth meridian roughly marks the line west of which the rainfall is too small to permit water percolating through the soil to be lost as drainage. East of this line the rainfall is great enough that water is lost by subterranean drainage. The amount of drainage water coming from soil varies in different parts of this region. Where the rainfall is heaviest and the evaporation least is the place where the maximum drainage is found. Here, too, is where the development of soil acidity is the most rapid.

Causes Contributing to Acidity

That soil acidity is so closely correlated with amount of rainfall immediately suggests that drainage may be the main cause of this condition. This has been shown to be the case. Analyses of the drainage water coming from soils show that it contains more bases than acids; thus soils are continually made poorer in basic elements and relatively richer in acid elements by the process of leaching. The basic element lost in greatest amount is calcium, which comprises 40 per cent of the weight of pure limestone rock. At the Cornell Experiment Station at Ithaca, New York, soils receiving no lime or chemical fertilizers lost by leaching from each acre the following amounts of bases annually:

*Loss of Bases in Drainage Water**

Calcium	177.1 pounds
Magnesium	33.8 pounds
Potassium	46.3 pounds
Sodium	83.5 pounds

Crops also remove bases from soils, but this is not so serious a matter in the development of acidity, because they also remove acid elements, such as sulfur and phosphorus. This tends to balance the losses of bases which occur from the same cause.

*Cornell Memoir 12.

Not only are bases lost from the soil in humid regions to a greater extent than are acid elements, but acid elements are also added to the soil in various ways. The fixation of atmospheric nitrogen which occurs in the soil, through the agency of bacteria, adds nitric acid to the soil. Certain other acid elements are carried into the soil by rain.

Of all the forces which under natural conditions tend to make soils acid, leaching is doubtless the most important, because of its selective action, in removing bases at a more rapid rate than it removes acid elements.

Effects of Acidity

The reaction of a soil—that is, whether it is alkaline, neutral, or acid—is one of the ecological factors which determines what kinds of plants can be grown on a particular soil. It is well known that alfalfa will not grow on an acid soil, and that certain ornamental plants like the rhododendron will not flourish unless the soil is acid.

Acidity affects plants in different ways and by different means. In the case of alfalfa, sweet clover, and many other plants, the bad effect of acidity seems to be proportional to the intensity of acidity. Soybeans, on the other hand, seem to be able to endure a high intensity of acidity, but are injured under acid conditions if this condition causes a high concentration of soluble aluminum in the soil solution. Acidity may also cause injury to some plants through the fact that under conditions of high acidity they are unable to absorb as much calcium as is needed for their normal growth. However, in any case the permanent remedy is to add lime to the soil in amounts sufficient to reduce the intensity of the acidity to a point where it is not detrimental to plants from any cause, direct or indirect.

Certain plant diseases are more virulent when present in an acid soil than they are in a neutral soil. Clubroot in cabbage is one of this class. In fact, clubroot can be prevented entirely by systematic liming of the soil. It is also believed that some of the organisms which are the immediate cause of corn root-rot thrive better in an acid soil than in a neutral soil.

Many desirable bacterial activities are adversely affected by the presence of acidity in the soil. Nitrification (the process by which nitrates are formed in the soil from other less available nitrogenous compounds), is seriously curtailed if the soil is low in lime. For this reason an application of lime to an acid soil often has the same effect on the following crop as an application of nitrate fertilizer.

Measuring Soil Acidity

At first there was little or no attempt made at estimating how acid the soil was. A little later, the question of how much lime was needed on a soil to correct the acid condition, commanded the attention of agronomists. Various methods were devised which were designed to answer this question. The answers obtained by these methods were usually referred to as the "lime requirement." As first defined, the lime requirement was the amount of lime needed to bring the reaction of the soil to the neutral point. Later it was found that it was not necessary to neutralize the acidity of

Storing ground limestone in a pile in the field is sometimes recommended, but it is well to remember that if it becomes wet it can be spread only with more or less annoyance.

a soil completely in order to grow many crops at their best, so that gradually the term "lime requirement" came to be used in connection with the specific crop in question. Thus the lime requirement for alfalfa was different on the same soil from the lime requirement for red clover. This has caused some confusion, but if we adhere to the policy of stating what plant we have in mind when we speak of lime requirement, confusion will be avoided.

The Litmus Test.—The use of litmus paper was the first widely used test for soil acidity. As a pioneer method it had value, but it gave little clue to the amount of lime which was needed on a soil. Furthermore, in the hands of one who does not appreciate the weaknesses of the method it may lead to wrong conclusions. In order that the test be of value, absolutely neutral litmus paper must be used. This is so sensitive to acidity that it is inadvisable to handle the paper with the hands, as there is enough acid in the perspiration to cause it to turn red. If les ssensitive paper is used the delicacy of the test is lost.

The Truog Test.—This is a test which has been extensively used, and has an advantage over the litmus test in that it is somewhat quantitative. As a field method it has certain objections, as will be noted. The test is made by using a definite amount of soil (10 grams) which is usually measured in a small vial. This is placed in an Erlenmeyer flask, and a definite amount of Truog's mixture (barium chloride and zinc sulfide) and distilled water are added. The flask is then shaken to mix the materials. When well mixed, it is heated to boiling over a flame, and after boiling one minute a strip of lead acetate paper is laid over the top of the flask, and the boiling continued for two minutes. If the soil is acid, hydrogen sulfide is evolved from the zinc sulfide. The amount of this that comes off determines the amount of blackening of the paper and measures the lime requirement. In other words, the lime requirement can be judged by the color of the paper.

The Thiocyanate Test.—This test was designed by the English soil scientist, Comber, and is a very convenient field test and quite reliable if good materials are used. The only reagent needed is a 4 per cent solution of potassium thiocyanate in alcohol, and the only apparatus needed is a small test tube or vial. About equal volumes of soil and the reagent are thoroughly mixed by shaking together. The tube is then set aside for about five minutes until the soil again settles, and some of the liquid comes to the top free from mirkiness. If the soil is acid the supernatant liquid will be red; the more acid the soil, the redder the liquid. By reference to a color chart the lime requirement can be estimated. The test is not well adapted to some highly organic soils, and often gives too low results on very sandy soils.

pH Value.—Another test of more recent origin as applied to soils is the determination of *p*H value. This test is a measure of the intensity of acidity. While in general the greater the lime requirement the lower will be the *p*H value, this is not always the case. The *p*H value is, however, a good measure of the injurious effects that may be expected from acidity. The *p*H scale is one in which a *p*H value of 7 is neutral. Acid soils have a *p*H value below 7 and alkaline soils have a *p*H value above 7. This test requires an expensive piece of apparatus and hence will never come into as popular use as the thiocyanate test, but it gives information concerning the intensity of acidity which is not given by any other test. It must be noted that intensity of acidity and lime requirement are two distinct things. The *p*H value might be described as bearing the same relation to lime requirement that temperature bears to the calories of heat contained in a body.

Adapting Crops to Acid Soils

It is a well known fact that crops respond differently to applications of lime. The reason for this difference is that crops differ widely in their tolerance to soil acidity. Observations in Ohio lead to selecting the following *p*H values as the minimum under which it is unsafe to attempt the crops listed if best results are to be expected:

pH Value Below Which Growth of the Following Crops Should Not Be Attempted

*p*H value	Crops
6.5	Alfalfa Sweet clover
6.0	Cabbage Cauliflower Lettuce Spinach Barley Sugar beets
5.5	Red clover Corn Wheat Cantaloups Timothy Canada field peas Kentucky bluegrass
5.0	Oats Soybeans Cowpeas Potatoes Tobacco Red top Canada bluegrass Alsike clover Mammoth clover
4.5	Strawberries Watermelons Buckwheat Rye

This suggests two ways of avoiding the bad effects of acid soils: (1) To lime the soil sufficiently to bring the pH value at least up to the minimum required for the crop in question; (2) to attempt to grow only those crops which can be grown well in a soil having a pH value as low as the one in question.

The last mentioned method probably has no place in a permanent scheme of agriculture where liming can be done at not too great a cost. It does, however, offer a path that may be safely followed by the man with limited means who must make the farm pay from the start. He can start with plants requiring only a relatively low pH value for their successful growth, and, as his finances permit, he can lime, thereby raising the pH value to the point where other plants which he may wish to grow will flourish. His farming, then, may be looked upon as an evolutionary process. He starts on an acid soil and is able to grow only acid-tolerant plants. If these are well chosen and he is a good farmer, they will be profitable. As he is able financially he may lime, bringing his soil to a higher pH value. Now, he can expand his list of crops and his profits should be greater. By following this scheme he will in time bring his soil to the point where he can grow the more acid-sensitive plants, and will have made the system pay as it goes.

In some sections it may never be profitable to lime to the extent that would be necessary if alfalfa were to be grown. In such a case it will be necessary to choose crops that will tolerate the pH value which it is decided will be the limit of profitable liming. Such cases occur in districts where liming is very expensive, because of no local supply and lack of railroad facilities.

Neutralizing Acidity

If the pH value of a soil is too low for the plants that are to be grown, this condition can be remedied by the addition of some basic substance. Many different substances might be used to bring about this result, but experience has shown that no substance is so well adapted to this purpose as some form of lime. Lye might be used to raise the pH value, but it would be expensive and it would also render the physical condition of the soil very bad. Soda would also serve to raise the pH value, but it would be as bad as lye in its effect on the physical structure of the soil. Lime is the only base which can be used with success for this purpose. Fortunately, lime is plentiful and is relatively cheap as compared with other bases.

Forms of Lime

There are three compounds of calcium which are loosely referred to as lime. They are calcium carbonate (limestone), calcium oxide (quicklime), and calcium hydroxide (hydrated lime). These are of value in neutralizing acidity in proportion to their content of the element calcium. The relative values of these substances, as neutralizers of acidity, can most plainly be seen if we show how one form might be changed into the others, the transformation being made so that the element of calcium remains constant in each succeeding form.

Limestone.—Limestone is the form in which liming material occurs in nature. As it is found in nature it is composed predominantly of calcium carbonate, but often contains magnesium carbonate as well as certain impurities that are worthless. When the content of magnesium is large, limestones are usually called dolomitic limestones. When pulverized, limestone is a valuable material for neutralizing soil acidity and is the most widely used material for this purpose in Ohio. The neutralizing value of pure limestone (calcium carbonate) is arbitrarily set at 100.

This method of taking limestone from the quarry has been replaced in the large quarries by steam shovels and steam trains, which accounts partly for their greater economy of operation.

Quicklime.—If we start with 100 pounds of pure limestone and heat this to a high temperature for a sufficiently long time, the limestone is changed to quicklime. The volume of the resulting product is the same as that of the limestone used at the start, but when we weigh the quicklime formed we find that it now weighs only 56 pounds. It has, therefore, lost 44 pounds in weight. This loss was occasioned by the fact that 44 pounds of a gas called carbon dioxide was driven off by the heat. This gas contains no calcium and therefore we have as our new compound a material more concentrated in calcium than was the limestone with which we started. It is as many times more concentrated than limestone as 56 is contained in 100 (100/56), or 1.786 times. Thus, pound for pound, quicklime is 1.786 times as valuable for neutralizing acidity as is limestone.

Hydrated Lime.—If we now add 18 pounds of water to the 56 pounds of quicklime, the lumps crumble to a powder. The material still remains dry, for the water has combined chemically with the lime, but the new compound weighs 18 plus 56, or 74 pounds. We have added no calcium in this slaking process and hence this 74 pounds of hydrated lime contains exactly the same amount of calcium which was contained in the original 100 pounds of limestone and the resultant 56 pounds of quicklime. It still weighs less than the original 100 pounds of limestone, and hence pound for pound it is as many times more concentrated in calcium as 74 is contained in 100 (100/74), or 1.35 times.

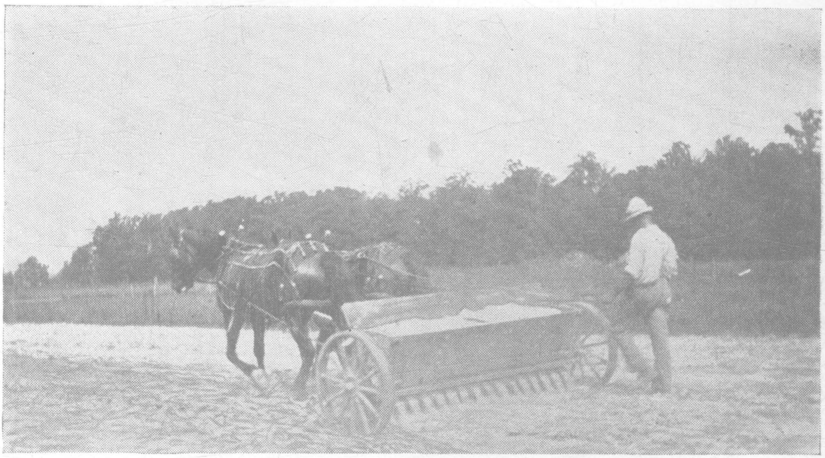
The Measure of Neutralizing Value

In making any measurement, some unit of measurement must be adopted. Thus in measuring distance we may use feet, or if the distance is great we may adopt the mile as our unit. In measuring the neutralizing power of liming material some unit of measurement must be adopted. In Ohio the unit commonly used, and which has been legally adopted for use in state control work, is calcium carbonate. This material, as stated before, is arbitrarily given the value of 100. Pure calcium oxide (quicklime) has a neutralizing value 1.786 times as great, so that its neutralizing value becomes 178 and pure calcium hydroxide (hydrated lime) becomes 135. From these figures it is easy to estimate what one can afford to pay for either quicklime or hydrated lime, if one knows the cost of a pure limestone. If a limestone which has a neutralizing value of 100 cost $4.00 delivered on the field where it was to be used, then one could afford to pay $4.00 times 1.35, or $5.40 a ton, for hydrated lime. On the basis of this same price for limestone, quicklime would be worth $4.00 times 1.786, or $7.14. A limestone having a neutralizing value of only 90 would be worth 0.9 times $4.00, or $3.60 per ton.

Magnesium Limestones

All limestones are not pure calcium carbonates. Some contain sand and clay, and other foreign matter. This, of course, dilutes them and their neutralizing power is therefore lower than that of a pure calcium carbonate. If the stone was composed of 50 per cent of foreign material such as sand, clay, or iron, its neutralizing power would be only 50.

Some limestones, however, possess a neutralizing power of more than 100. This fact is sometimes puzzling to farmers. It comes about through the fact that such limestones are composed of a mixture of calcium carbonate and magnesium carbonate. Magnesium carbonate is more concentrated in neutralizing power than is calcium carbonate, and hence when it is mixed with the calcium carbonate it raises the neutralizing power higher than that of a pure calcium carbonate. Eighty-four pounds of magnesium carbonate will neutralize as much acid as 100 pounds of calcium car-



A good job of spreading lime can best be accomplished by the use of a machine especially designed for that purpose.

bonate. Hence the neutralizing power of a pure magnesium carbonate would be 100/84, or 1.19 times as great as that of calcium carbonate, therefore it may be said to have a total neutralizing power of 1.19×100, or 119. If a limestone were composed of equal parts of calcium carbonate and magnesium carbonate the total neutralizing power of the mixture would be $100+119 \div 2$, or $109\frac{1}{2}$. Further consideration of the value of magnesian limestone will be reserved for a later paragraph.

Fineness of Limestone

In the preceding comparison of limestone with other forms of lime, it has been assumed that the limestone is of sufficient fineness to be of optimum value. Fineness is very important in considering the effectiveness of limestone. If the stone is coarse it has a relatively small surface exposed, but if it is reduced to a fine powder its surface is increased greatly. Limestone which will just pass a 100-mesh sieve offers ten times as much surface as the same weight of stone that will just pass a 10-mesh sieve. Or to state the law generally; if the mass is kept constant and the shape of the particles the same, the surface exposed varies inversely as any linear dimension. Thus, reducing the diameters of spherical particles 100 times increases the surface 100 times.

Experiments thus far do not indicate that the value of a limestone is indefinitely increased as the fineness is increased. Apparently when a certain degree of fineness is reached, some other factor, inherent in the soil, enters, and increasing the fineness increases the value of the material no further. More information is needed on just how fine limestone should be for optimum results, but our present information convinces us that when it is fine enough that 30 per cent will pass a 100-mesh sieve, 50 per cent will pass a 50-mesh sieve, and 95 per cent will pass a 10-mesh sieve, it is very satisfactory liming material. Material of this fineness may legally be called "Agricultural Ground Limestone" in Ohio. The value of coarser material must be discounted.

On very acid soils the use of lime makes possible the growth of clover. Foreground not limed. Background limed.

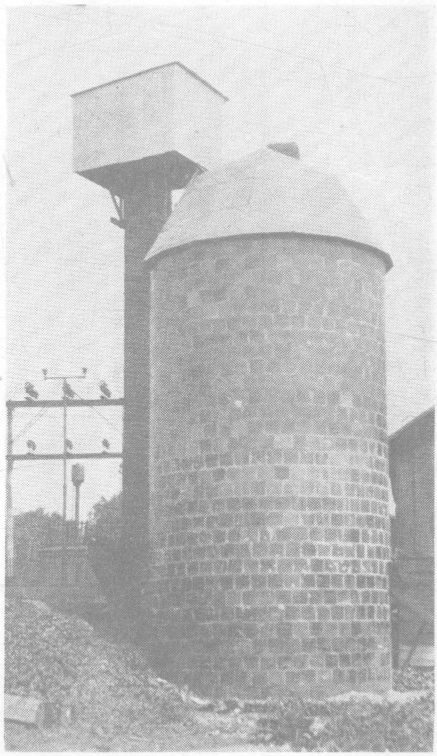
Based on this belief, the Ohio Limestone Law has recognized three types of limestone, based entirely on fineness. The following table gives the specified fineness necessary for each class.

Legal Fineness of Limestone Forms in Ohio

	Per cent that will pass through a sieve of				
	100 mesh	50 mesh	10 mesh	4 mesh	3 mesh
Agricultural ground limestone	30	50	95		
Agricultural limestone meal	20	30	80	100	
Agricultural limestone screenings					100

How Composition and Fineness Affect Rate of Solution

As the lime in the soil must first go into solution before it can react chemically with the acid constituents in the soil, the rate of solution of liming materials is important. In general, the finer the particles the more rapid the rate of solution. However, there is a difference in the way stones of different composition act in this particular. Coarse limestones which are high in magnesium carbonate (dolomitic limestones) dissolve much more slowly than stones of the same fineness high in calcium carbonate and low in magnesium carbonate. Thus, if one were using screenings, a high calcium stone would be preferable from the standpoint of rate of neutralization of soil acids. With finely ground stones there is much less difference in the rate of solution between high calcium stones and high magnesium stones.

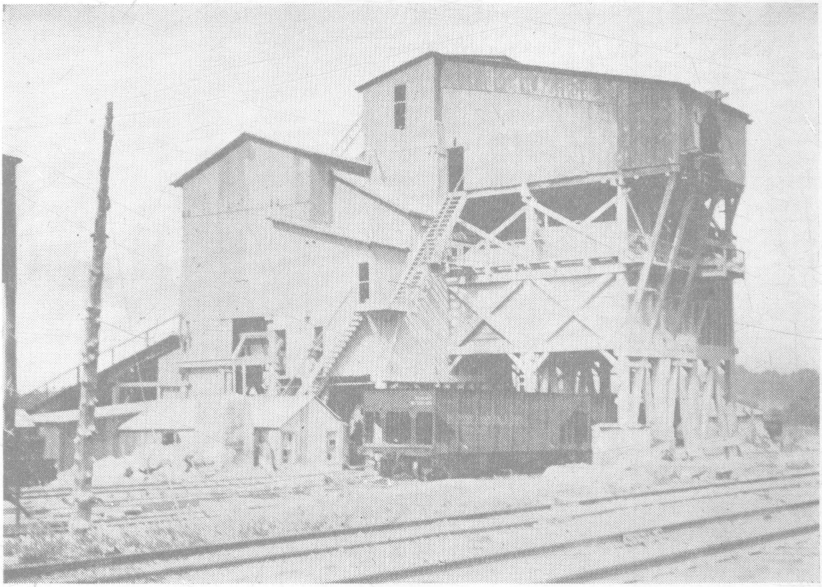


The silo type storage bin is proving most popular in Ohio.

Dolomitic Stones Sometimes Preferable

Experiments in Ohio show very good results from the use of finely ground dolomitic limestones. As stated before, of two stones equally free from foreign material the one containing the higher content of magnesium carbonate will have the higher neutralizing value. Therefore, if the material is finely ground there is no reason to discriminate against a stone because it contains a high percentage of magnesium carbonate. In fact, in some sections of the United States, dolomitic limestones are in demand for liming material, in order to furnish magnesium as a plant food. Thus, in some of the tobacco regions of North Carolina, it is found that dolomitic limestones are effective in preventing chlorosis in tobacco.

There are a few places in the world where the soil seems to contain an excessive amount of magnesium in proportion to its calcium content. In such localities the use of dolomitic limestones have not given as good results as high calcium limestones. No such results have ever been reported in Ohio.



Large producing plant from which car-load shipments are made.

Securing Liming Material

There are four general methods of securing liming material. They are:

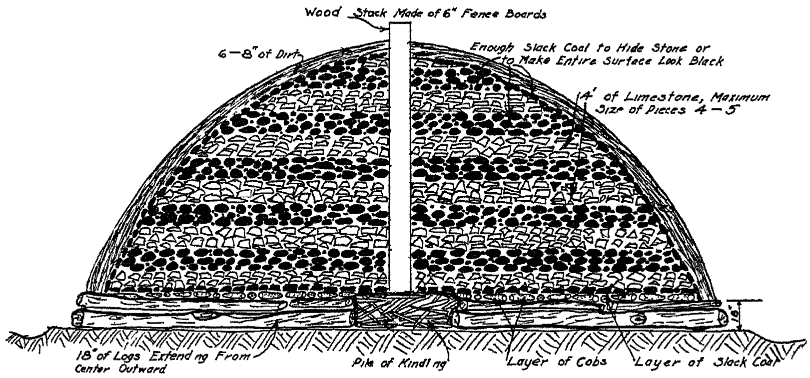
1. Buying from some large producing plant and shipping to the place where it is to be used.
2. Production at some centrally located, local limestone outcrop, from which it can be hauled by wagon to the field.
3. Grinding on the farm with a portable crusher.
4. Burning the lime in a stack or kiln.

These four methods of securing liming material vary in their relative desirabilities. The right choice depends on conditions.

Buying from Large Producing Plants.—Where there are good railroad facilities, it will usually be found the cheapest to have the lime shipped from some large producing plant. These plants are able to produce their product enough more cheaply so that even when the freight is added it delivers at a price below the cost of production at small community plants.

Community Production.—Where railroad facilities are not at hand, one of the other three methods may prove the best if there is a local supply of limestone available. If a large, centrally located outcrop is available in a community the second method of securing liming material will usually prove best in communities needing lime and not well served by railroads.

Portable Crusher.—The portable crusher offers possibilities when the conditions demanded by the first or second methods are



Hemispherical stack for burning lime

not met. This method is used successfully in many communities, but it cannot compete with either of the first two methods where one of these is feasible.

Burning Lime in a Stack.—Satisfactory liming material can be produced by burning in a stack when cheap fuel is available. By this method the chief outlay is labor.

A lime stack may be built on any level piece of land. It may be burned in the field where the lime is to be used. A convenient form is illustrated by the accompanying diagram. The diagram shows a cross-section of a hemispherical stack. Where the stack is large it may be necessary to build it in the form of a flattened hemisphere.

When the stack has been built, a fire may be started at the center of the base by pouring some kerosene down the wooden stack to the pile of kindling and then throwing down a blazing fire brand. Fires should also be started at from four to six other points around the outside of the pile. As the pile burns, "cave-ins" will occur daily. These should be covered with earth as soon as discovered to prevent the escape of heat.

In building the stack, care should be taken to place relatively small pieces of limestone near the outside. Pieces 8 inches in diameter may be left whole if placed near the center of the stack where the temperature will be the highest. After firing, about 3 weeks must usually elapse before the pile is burned out and cooled sufficiently to be opened.

If opened before the lumps of quicklime have slaked, it is possible to separate much of the soil from the lime and save handling it. If allowed to lie in the pile until slaked, separation of lime and the earth covering will be impossible.

Will Liming Pay as Well or Better Than Fertilizer?

Liming will pay if the soil is acid and the lime is bought at not too high a price. The question is often asked, "Which should one buy, lime or fertilizer?" assuming that the farmer has only enough money to buy one. The Ohio Experiment Station has accumulated some data collected over a period of many years which answers this question conclusively for soils similar in their requirements to those at Wooster, and should apply generally to all acid soils in Ohio.*

"In a five-year rotation of corn, oats, wheat, clover, and timothy the average value of the crops less the cost of lime has been $79.16 per acre on plots which received lime but no fertilizer. On the fertilized but unlimed plots the value of the crops less the cost of fertilizer has been $46.57. Stating the case differently, limestone alone has increased the crops 183 per cent, while fertilizer alone has increased the crops 145 per cent. The percentage increases in yield from fertilizer have been greatest on wheat crops and least on hay."

It would seem, therefore, that for the man who counts his profits over the whole period of a rotation, lime alone is a better investment than fertilizer alone. For the renter who counts his profits as one year's grain crop only, the case may be reversed and fertilizer may be a better investment than lime. It is well, however, to keep in mind that the best results can be obtained only when both lime and fertilizer are used on soils that are acid in reaction. Fertilizer gives its best results on limed land, and lime is not a satisfactory substitute for fertilizer.

*Ohio Exp. Sta. Bul. 382, p. 19.